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An influence of Mg adsorption on the Si(5 5 12) substrate conductivity and surface morphology

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Abstract

Influence of thickness of magnesium coverage deposited at room temperature and 100 ^{O}C on the atomically-clean surface Si(5 5 12)-2x1 on the electrical properties and morphology of the sample was investigated. It was established that deposition of Mg at room temperature results in formation of nanowires in the direction [-110] on silicon along narrow terraces formed after the high temperature cleaning of the substrate. The nanowires have high conductance leading to increasing of overall conductance on 13-15 % at Mg thickness of 4 monolayers (0.8 nm). Growth of Mg at 100 ^{O}C results in the formation of disordered islands of magnesium silicide. In this case changing of conductance does not occur because of low conductivity of the silicide.

Keywords: magnesium; Si(5 5 12); conductance

1. Introduction

Surface silicon reconstructions were investigated for a long time. It gave rise to the formation of various surface phases and different nanostructures [1, 2]. Silicon surfaces with (111) and (100)

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orientation were intensively studied with the view of formation of new superstructures resulted in construction of 2D phase diagrams [1]. Among these reconstructions a specific interest reveals nanowires which could be grown in specific directions on silicon surface. It is known that high index (5 5 12) surface represents periodical one dimensional rows oriented along [-110] direction [3]. Surface reconstructions of such substrates induced by metal correspond to the trenches of various widths [4]. Some investigations were conducted in this field using Au, Ag and Sb [5-8]. In this paper we studied formation and electrical properties of Mg superstructures grown on the silicon (5 5 12).

2. Experiment

All experiments were performed in the ultrahigh vacuum chamber with the base pressure $2\cdot10^{-9}$ Torr equipped with low electron energy diffraction analyzer (LEED), an attachment for *in situ* electrical measurements [9], quartz microbalance and sublimation sources of silicon and magnesium. Samples were cut from the Si(5 5 12) n-type wafer of 15-20 Ohm·cm conductivity. High temperature cleaning of a sample was performed by direct current flash at 1250 ^{O}C followed by slow cooling down from 900 to 400 ^{O}C. After the cleaning process a sharp LEED pattern corresponding to atomically clean Si(5 5 12)-2x1 surface was registered. Magnesium deposition rate was varied from 0.2 to 1.0 nm/min depended of experimental conditions. *In situ* electrical measurements were performed at room temperature regardless of Mg deposition temperature. Surface morphology of the grown samples was investigated right after the unloading from vacuum chamber with atomic force microscope (AFM) Solver P47 in tapping mode.

3. Results and discussions

In this work we performed two series of experiments. In the first one Mg was deposited on the silicon at room temperature (RT). Magnesium thickness was 2 monolayers (1 monolayer was taken as 0.2 nm). Surface morphology is presented in the Fig. 1(a). One can notice a horizontal stripes along [-110] direction which are the guide for an elongate islands. Fig. 1(b) shows the same area as in the previous figure recorded in the spread resistance mode of the microscope. The brighter color in this image the higher conductance of the corresponding site on the real surface. It is clear, that areas of high conductance in Fig. 1(b) match to the islands in Fig. 1(a). Therefore at room temperature Mg atoms are gathered along [-110] direction and form extended islands with high conductance.

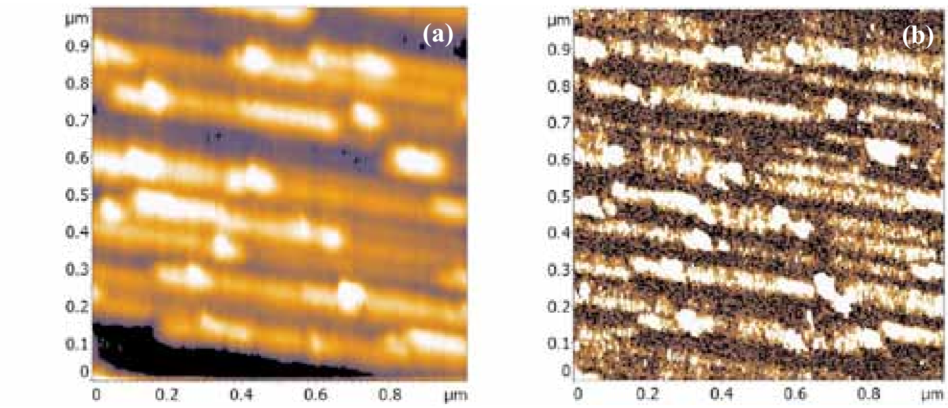

Fig.1. AFM image of Si(5 5 12) with 2 monolayers of Mg deposited at RT. The same area was registered in tapping mode (a) and in spread resistance mode (b)

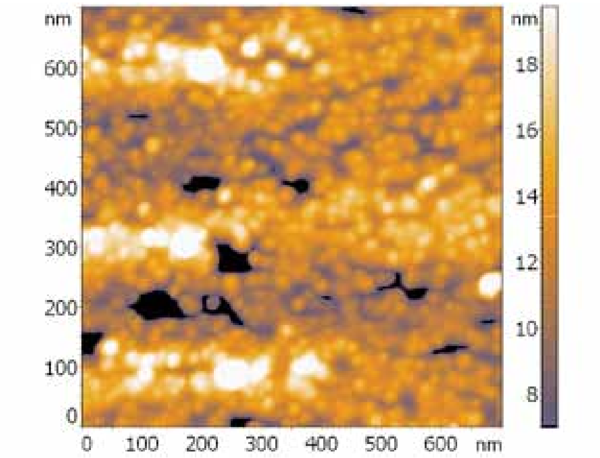

Fig.2. AFM image of Si(5 5 12) with 4 monolayers of Mg deposited at 100 ^{O}C

In the case of deposition on the silicon at 100 ^{O}C Mg atoms agglomerate into the separated disordered islands and do not form conducting objects (Fig. 2). Apparently magnesium reacts with the silicon at this temperature resulting in formation of silicide. Earlier we observed such effect using Auger electron spectroscopy and electron energy loss spectroscopy [10].

The main goal of the second series of experiment was *in situ* investigation of electrical properties of samples prepared at the same conditions. First, we performed repetitive deposition of small Mg portions up to 4 monolayers (Ml) on silicon at room temperature (Fig. 3). Increasing of Mg thickness to 1.5 Ml leads to the noticeable increasing of conductance and further tends to saturation. An additional sample was prepared and investigated with AFM to check the surface state. Some conductive paths along [-110] direction were find out similar to Fig.1(b). Therefore, additional conductance is explained by formation of nanowires on the silicon surface.

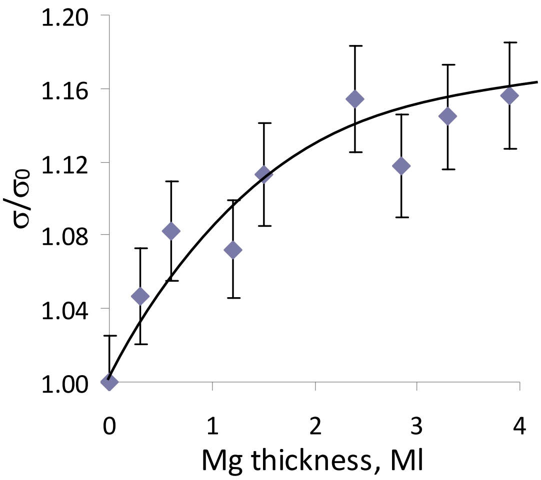

Fig.3. Relative changing of conductance with Mg thickness. Conductance of clean Si(5 5 12) is taken as initial value

Investigation of transport properties of Mg deposited at 100 ^{O}C revealed completely different character of electrical properties vs. Mg thickness. It was find out that conductance and mobility of majority carriers are almost independent from magnesium coverage. Most likely it is explained by low conductance of magnesium silicide. Moreover, it correlates with island growth mode registered by AFM (Fig.2). Formation of separated silicide islands and absence of continuous film even at the coverage of 4 Ml does not create additional conductivity channel so electrical properties of the whole system stay unchanged.

4. Conclusions

Using *in situ* electrical measurements and *ex situ* atomic force microscopy in tapping and spread resistance mode we investigated initial stages (up to 4 Ml) of magnesium growth on high index silicon surface at room and elevated temperatures. It was found that Mg atoms on Si(5 5 12) at RT form highly conductive paths on the surface. At the maximum coverage overall conductance increases on 13-15 %. At 100 ^{O}C magnesium reacts with the substrate and silicide formation takes place resulted it island growth mode. In the studied range of thickness these islands do not coalescence.

Acknowledgements

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